ACCELERATING THE FAN EXPERIENCE

How FORMULA 1® is driving the future of racing using machine learning and the AWS Cloud

Official Sponsor

My earliest memories of racing date back to when I was young, living in Middlesbrough, watching my Dad glued to the screen every time the Formula 1 was on TV. It wasn't long before I was hooked, too, and desperately wanted to be an engineer in this beautiful world of sporting art and engineering excellence. After university, I had my first role in racecar design with Mike Pilbeam, the ex BRM F1 design chief, which kicked off my career with formula racing.

The sport has changed a lot since my early days, but the one constant has always been the spirit of innovation built into everything we do. We are constantly innovating, all day, every day; it is a part of the DNA of an F1 engineer. The innovation lands across all areas of technology within F1, but it is also hugely important to understand the human element. It is the people—and their spirit of innovation—that are responsible for both fast racing cars and efficient organizations. As engineers, we have to have a very close relationships with our drivers. Like the machinery they drive, we must understand how to get the best out of them. The drivers are the ones executing their skills on the track, but we feel an immense responsibility both for their success and the success of the team, as well as for their safety.

My first experiences with telemetry data in racing started in the mid-'90s, but data has never been more critical to the sport than it is today. With telemetry data collected from every car and on every track, F1 has been able to make massive improvements to make the sport more interesting for fans and safer for drivers. It is the very essence of data analytics that has led us as an organization to the 2021 rules, which we hope deliver a more exciting, a more engaging, and more insightful Formula 1. If I can play a small part in that journey of bringing a better Formula 1 to our fans with data, it will be a great honor. Therefore, after spending 11 years at Ferrari, five years as head of vehicle performance at Williams, and 25 years in total within the Formula 1 teams, I'm now working directly with F1 as their director of data systems.

This has put me in close proximity to the work F1 is building on AWS, much of it leveraging their machine learning and AI in exciting new ways. Formula 1 and AWS both have problem-solving in their DNA. AWS employs what they call a "working backwards model," which forces them to start with the customer and the problems they're solving for rather than trying to fit a use case or product somewhere it doesn't belong. I immediately identified with the engineers at AWS—they clearly get it, and they're invested in breaking new ground for their customers.

We have a robust roadmap ahead of us, and I'm excited to see where this partnership evolves. But this work isn't just aspirational; it's active. We've already worked with AWS to develop F1 Insights; now in its second racing season, and among a number of other projects, we're improving vehicle design to increase wheel-to-wheel action, using advances in high performance computing. It's just the start. But we're excited to bring you along. Buckle up.

Rob Smedley
Director of Data Systems, Formula 1

TECHNOLOGY AS A SPORT

Over 100 years ago in France, drivers and automotive engineers started pushing the limits of automotive technology, first with speed tests, then with endurance challenges, and eventually on purpose-built circuits and closed city streets in front of live audiences.

These early races evolved into what we now know as Formula 1, in some ways making F1 racing the longest-running technology competition, with no other sport as dynamic in both its evolution and embrace of new technology. Officially, F1 turns 70 years old this year and remains one of the few sports that combines real-time skill with engineering and technical prowess, where the evolution of the rules and tools is not seen as a bug but a feature, built into the DNA of the sport. This keeps a growing base of over 500 million fans engaged and drivers and teams always pushing as races are won and lost in tenths of a second.

A GRAND HISTORY OF RACING TECHNOLOGY

The Grandes Épreuves ("Grand Trial") was the first official predecessor to F1 to combine the European Grand Prix with the Indy 500, forming the foundations of the international championship in 1906 to denote up to the eight most important racing events of the year.

Early races were heavily nationalistic, with auto manufacturers often representing country of origin and rules varying country to country. But even at the time, engineers had to innovate around restrictions on engine size, usually no more than four cylinders, producing less than 50 horsepower. The driver carried a dedicated mechanic as a passenger, and only these two were allowed to work on the car during a race. From the beginning, technology and an understanding of the mechanics of racing and vehicle maintenance were embedded into the sport.

Technology evolved each decade; the winner of the 1906 Grand Prix, Renault, took the title in large part to its working with Michelin to develop the first detachable wheel rims that didn't require prying off and replacing pneumatic tires.

For the next 24 years, regulations on technology would include the first "formulas" of engine size and vehicle weight, with fluctuating periods of both heavy regulations and near lawlessness.

1935 Dieppe Grand Prix
Dieppe, France. 21 July 1935

TIMELINE
A History of Formula 1® technology

1902
Renault introduces drum brakes to replace band brakes

1904
Fédération Internationale de l'Automobile (FIA) is formed to represent the interests of motoring organizations

EVOLUTION, NOT REVOLUTION

In 1950, the FIA, or Fédération Internationale de l'Automobile, established a series of new racing championships and concurrent international regulations, including Formula 1 and Formula 2 and the first FIA Formula One World Championship. This was the beginning of the F1 that we know today.

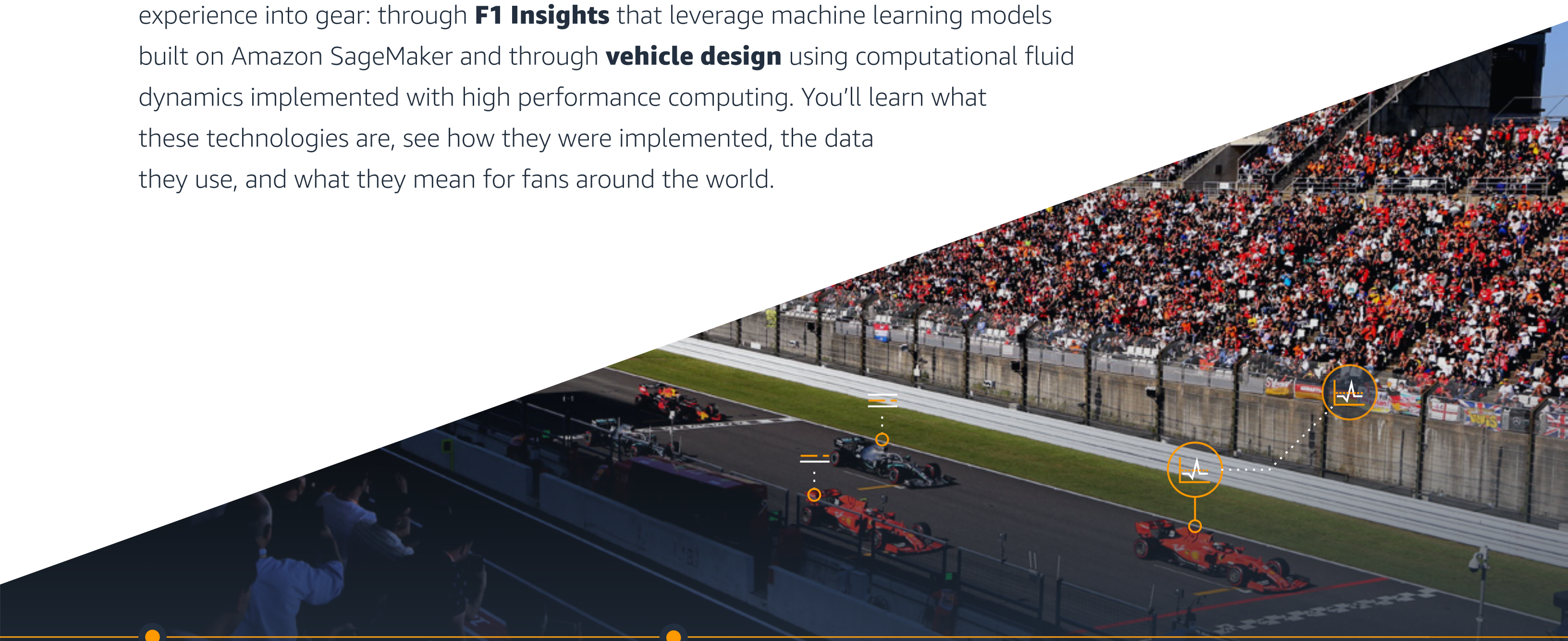
The next 60 years saw developments and innovations in vehicle body designs and aerodynamics, body materials, tire compounds, engine builds, steering, fuel, and in particular various safety requirements and standards often lobbied for by the drivers themselves (see timeline at the bottom of each page).

With safety standards at an all-time high, 2011 and on saw a massive investment and cultural shift in F1 to increase the action on the track for racing fans. Indeed, with pit stops under 2 seconds, drivers braking and tearing around tight corners with up to 5 g force, and speeds up to an insane 375 kph (233 mph), today's F1 is quite the spectacle.

WORKING WITH AWS

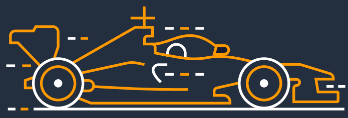
Through a partnership with AWS announced in 2018, F1 is enhancing the fan experience through vehicle design changes and an improved understanding of what happens on and off the track through the power of data and analytics.

In this eBook, we'll explore two of the most exciting ways that F1 is shifting the fan experience into gear: through **F1 Insights** that leverage machine learning models built on Amazon SageMaker and through **vehicle design** using computational fluid dynamics implemented with high performance computing. You'll learn what these technologies are, see how they were implemented, the data they use, and what they mean for fans around the world.



1906
The Grandes Épreuves ("Grand Trials") are first to combine the European Grand Prix and Indy 500

1906
Michelin introduces removable rims at the Grand Prix de l'Automobile Club de France, or French Grand Prix, reducing tire change time from 15 minutes to around four minutes

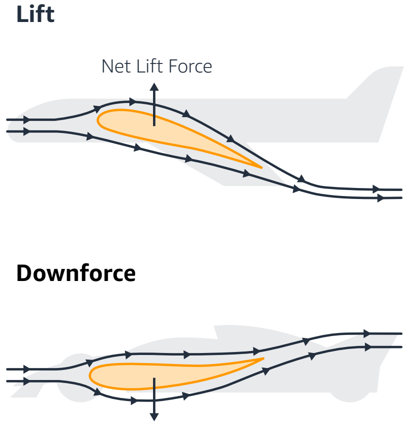


ACTION ON THE TRACK

OVERTAKE IS KING

Working backwards from a desire to improve the F1 fan experience, the AWS team needed to understand what makes F1 so exciting to watch.

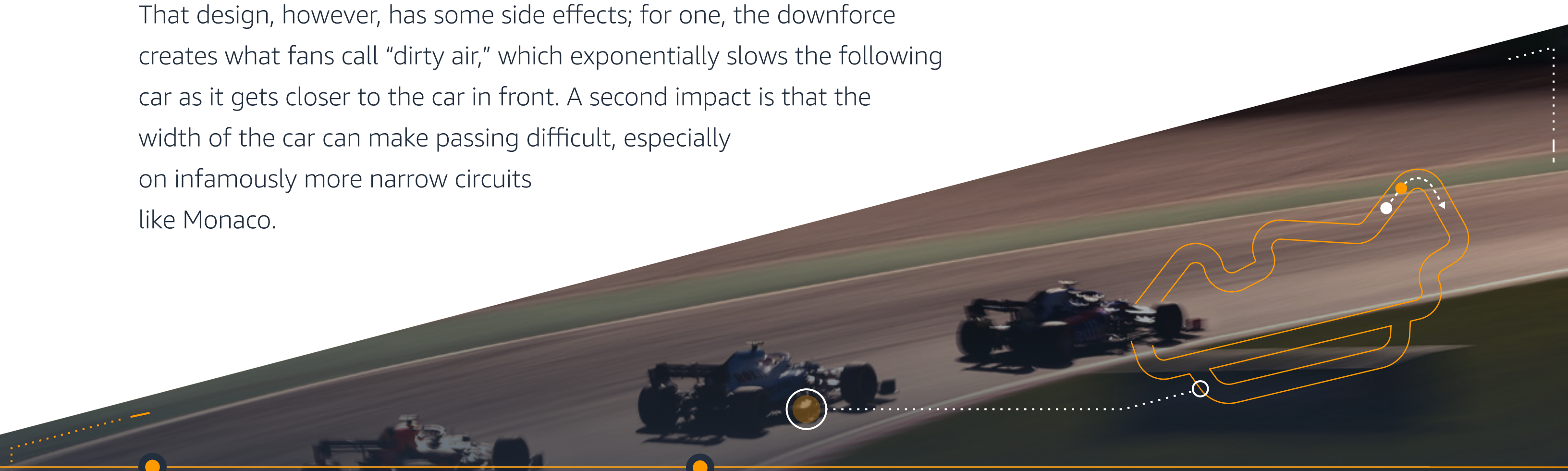
Overtakes happen when a following car achieves the lead position over another. We'll explore the roles that downforce and pit strategy play in successful overtakes, which will provide context for the initiatives F1 decided to prioritize in working with AWS.



UNDERSTANDING DOWNFORCE

Overtake attempts often happen at turns, and due to the sinuous F1 circuits, opportunities are far less frequent than in the ovals of stock car races. When a following car is in an overtake position, a number of factors are considered. Part of the thrill of F1 is the top speeds and 5 g cornering and braking, made possible by increased downforce. Airplane wings are designed to create lift—to push air under the wings and pull the aircraft upward. F1 racecars are designed with the opposite in mind—they're built wide, with aerodynamics meant to push the car toward the ground, adding stability and grip at high speeds.

That design, however, has some side effects; for one, the downforce creates what fans call "dirty air," which exponentially slows the following car as it gets closer to the car in front. A second impact is that the width of the car can make passing difficult, especially on infamously more narrow circuits like Monaco.



1926
Riding mechanics are no longer required in the car

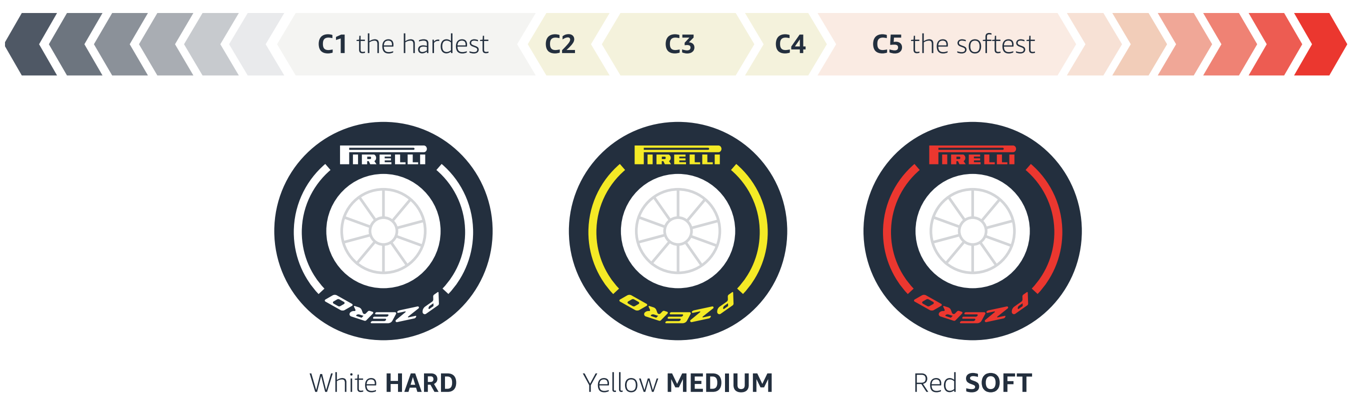
1946
Formula 1 becomes officially recognized formula

When a driver defies these odds in this incredibly complex maneuver, it is a showcase of their skill, their temperament in what amounts to split-second decision making, a bit of luck, and how the team strategically manages tire wear and maintenance through what is called the team's pit strategy.

PIT STRATEGY

Teams are allowed three dry tire compounds (or two wet compounds for rainy conditions) and must use at least two during each race, which requires at least one pit stop. The different compounds balance performance and resilience; softer compounds provide superior grip and handling in exchange for faster degradation, and harder compounds provide superior durability but limit cornering speed and traction. Drivers and teams decide when and how often to pit, which beyond tire replacement may include other repair needs or adjustments.

Fresh tires can boost performance, and a softer set might help a driver overtake a vehicle with harder tires with more wear. But pitting too early can cost a driver's position, and the new leader can enjoy the open track to gain enough distance to safely pit on the next lap. Pirelli provides three different compounds of slick tires at each race, with five compounds available in its tire range. They are numbered C1 to C5, with C1 being the hardest and C5 being the softest. The compounds were designed to increase resistance to overheating and provide greater consistency over the course of a stint.



1950
The launch of the FIA Formula 1 drivers' World Championship with the first Formula 1 race at the British Grand Prix at Silverstone on May 13. Official F1 cars have front engines and wood and metal steering wheels

1954
New F1 regulations limit engines to 2.5 liters

FAN ENGAGEMENT

F1® INSIGHTS

Critical real-time decisions can lead to outcomes down to a tenth of a second, and often those choices are nearly invisible to fans, who try to piece together the significance of a particular strategy or maneuver by listening to the commentator and the live feed between the team and its driver. The driver must also possess intimate knowledge of their car, navigating dozens of parameters through over 30 buttons on the steering wheel controlling things like torque curve, air-fuel mix, and differential settings, all of which will be changed several times on the fly throughout a race. With 20 drivers and 10 teams on the track at once, it can be a lot for a fan.

Enter F1 Insights, developed with the **Amazon ML Solutions Lab** and the **AWS Professional Services** teams. Already rich with both analog and digital data, F1 and AWS worked together to harness that data, working backwards from desired organizational outcomes for F1. We'll look at two in particular that leverage predictive machine learning models built on Amazon SageMaker, but first, let's explore how the data is collected.

DATA COLLECTION

Each racecar is outfitted with over 120 sensors, which generate over 1.1 million telemetry data points per second transmitted from the cars to the pits during a Grand Prix. These monitor everything from the car's speed and acceleration to the steering angle to the charge in the energy recovery system to the mass of fuel used to the status of its drag reduction system.

Individual teams have been using this trove of trackside and telemetry data in different ways, but F1 started with a unique organizational challenge—use the data to engage fans during the race. Here's where two graphics come in—Pit Strategy Battle and Battle Forecast.

> "With the speed and compute power from AWS, the potential of man and machine is unlike anything we've ever experienced in F1."
>
> **Ross Brawn**
> Managing Director, Motorsports

1957
The Cooper team features the first rear-engine F1 car in a race. Within four years, all cars will feature this design

1961
New F1 regulations limit engines to 1.5 liters

PIT STRATEGY BATTLE

Undercutting and overcutting are strategies used by F1 teams during close racing scenarios to gain a lead over a rival, with the margin between success and failure measured in tenths of a second.

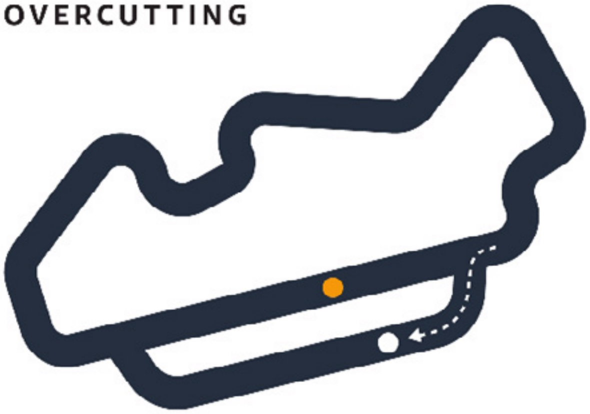
In an **undercut**, the chase car pits early in an attempt to gain ground, with fresh tires, on the lead car once the lead car needs to pit on the next lap.

In an **overcut**, the chase car pushes the limits of their tires, letting the lead car pit first, giving them the advantage of both the lead and an empty track with clean air. If they can gain enough lead over the course of the next lap, they might be able to maintain their lead position when they finally pit.

Pit Strategy Battle is a graphic that provides fans and commentators with real-time insight on the position of the two rival drivers, the predicted gap after their respective pit stops, and the percentage chance of an overtake, helping fans to assess how successful each driver's strategy will be in real time and its potential outcome.

UNDERCUTTING

OVERCUTTING



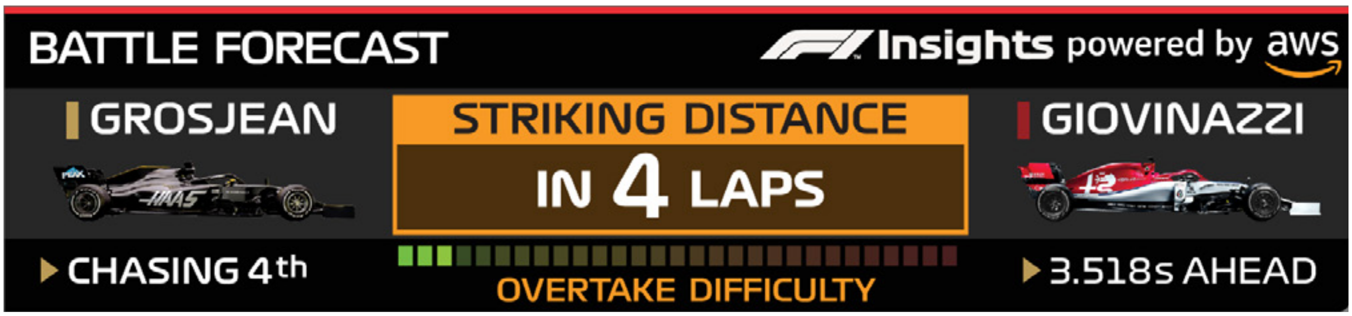
1962
Lotus ditches load-bearing internal frame and, inspired by aircraft, introduces an aluminum sheet monocoque chassis, reducing weight and distributing tension and compression across the surface

1966
New F1 regulations allow engines up to 3 liters

BATTLE FORECAST

Throughout F1 history, some of the most exciting racing action on track has come from driver "battles" —when a chasing driver gets close enough to attempt an overtake, as described earlier. The resulting fight for position results in an unpredictable and sometimes dangerous combination of offensive and defensive driving action between the drivers involved.

The Battle Forecast graphic analyzes track history and projected driver pace, using machine learning models built on Amazon SageMaker to provide insights into developing driver battles during the race that are not always obvious to the audience, like striking distance and predicted overtake difficulty.



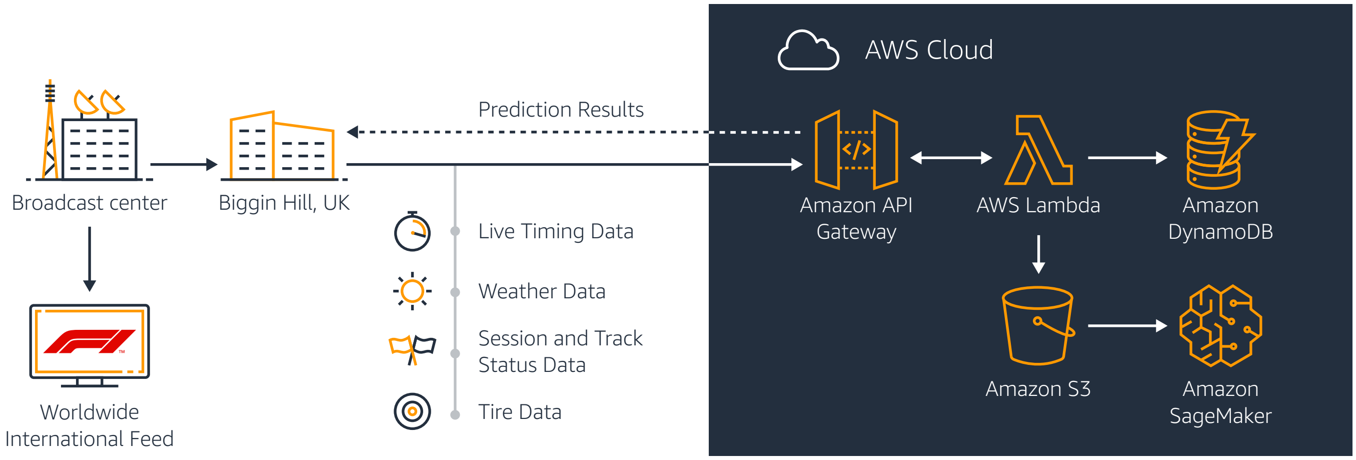
USING MACHINE LEARNING

By partnering with the Amazon Professional Services (ProServ) team, F1 was able to work with AWS from a diverse set of strategic outcomes and goals to align various stakeholders. The ProServ team used notebooks in Amazon SageMaker to analyze and visualize large quantities of timing, tire, and weather data uploaded to Amazon S3 to understand how the race looks from an algorithm's point of view. The team analyzed strategies and outcomes from past races and debated which historical data points would be most valuable to extract and ingest into ML models, as well as which data points might be most valuable to include in real time during a race.

Having cleaned all relevant data from various sources, the team quickly set business and technical key performance indicators (KPIs), technical requirements, and output formats to be used in validation code that allow for quick experimentation with feature engineering and various algorithms to optimize for the prediction error.

1967
The German Grand Prix is first to be televised in color

1977
Renault produces the first turbocharged car, which will later be banned in 1989



Using cloud-native AWS services and the pay-as-you-go model allowed the team to keep costs relatively low. Once a signal is captured at the race track, it begins its journey, first passing through F1 infrastructure to an HTTP call to the AWS Cloud. The team used Amazon API Gateway to act at the entry point to the application, which was itself hosted as a function in AWS Lambda to implement the race logic. Once the function received the incoming message, it would first update the race state stored in Amazon DynamoDB (for example, change of driver position). If the function determined that it was a trigger for a prediction, it would use the model trained in Amazon SageMaker to make and return the prediction as a response to the call, ingested back through F1 infrastructure to the broadcasting center, ready to be used by the race director. All in less than 500 milliseconds.

When designing the machine learning architecture, the team would need to optimize for accuracy and runtime performance, requiring tools that would keep costs down while enabling rapid experimentation.

By carefully analyzing racing data and model predictions, the team was able to extract features from the available race data, and once the models were built, the team trained them using historic race data leveraging the Amazon SageMaker feature called Training Jobs, which fully and automatically implements provisioning and deprovisioning of resources, so the data scientists could focus on the optimization of the model.

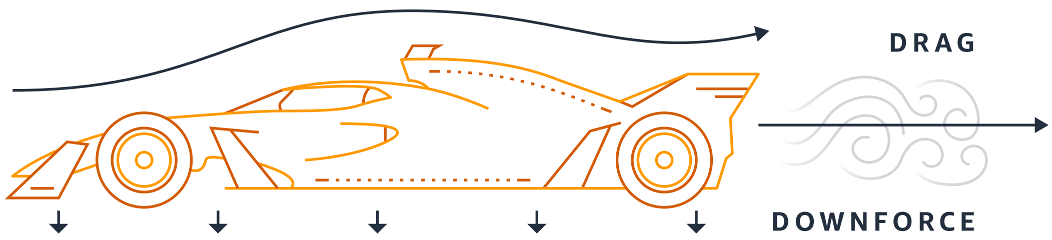
Although training time of the algorithms was fairly straightforward, inference had to happen in real time; F1 serves a livestream to hundreds of millions of viewers around the world, and for a sport that is being decided in milliseconds, data that is even a few seconds old is obsolete. To meet the required response time, the team loaded the models trained with historical race data back into Amazon SageMaker into the application hosted on AWS Lambda. Since the model stayed loaded in memory right next to the running code, it allowed them to cut the invocation overhead to a bare minimum. The team then used the Amazon SageMaker built-in popular, efficient, and open-source algorithm XGBoost to further train the model. Hosting the application and models in Lambda allowed them to scale the infrastructure elastically and easily, keeping up with the varying rates of predictions during the race without operational interventions.

1981
McLaren unveils the MP4, the first carbon fiber-reinforced chassis, and later inspiration for McLaren's F1, the first carbon fiber monocoque production car

AERODYNAMICS

VEHICLE DESIGN

As discussed earlier, the emphasis on downforce pushes the car into the track for increased grip and, ultimately, higher cornering speeds. But those same corners are where cars need to be close to make overtakes happen, and the current generation of cars suffer a significant loss of downforce when running in the wake of another car.



The inability to sustain close racing reduces the chance of overtaking, so pole positions often become predictable indicators of the race winner. And when the same drivers win every time, it has a significant negative impact on the fan experience. This means that F1, already having to historically balance safety with speed, has needed to contend with a third major variable: competitiveness on the track.

F1 Director of Data Systems, Rob Smedley, explains: “When we engaged our fan base, and we asked them ‘what do you want,’ the biggest thing that everybody wants is more wheel to wheel racing… to see the cars inches from each other.”

By increasing opportunities for drivers to attempt the thrilling maneuvers that showcase their skills, F1 would also be increasing their opportunities to win.

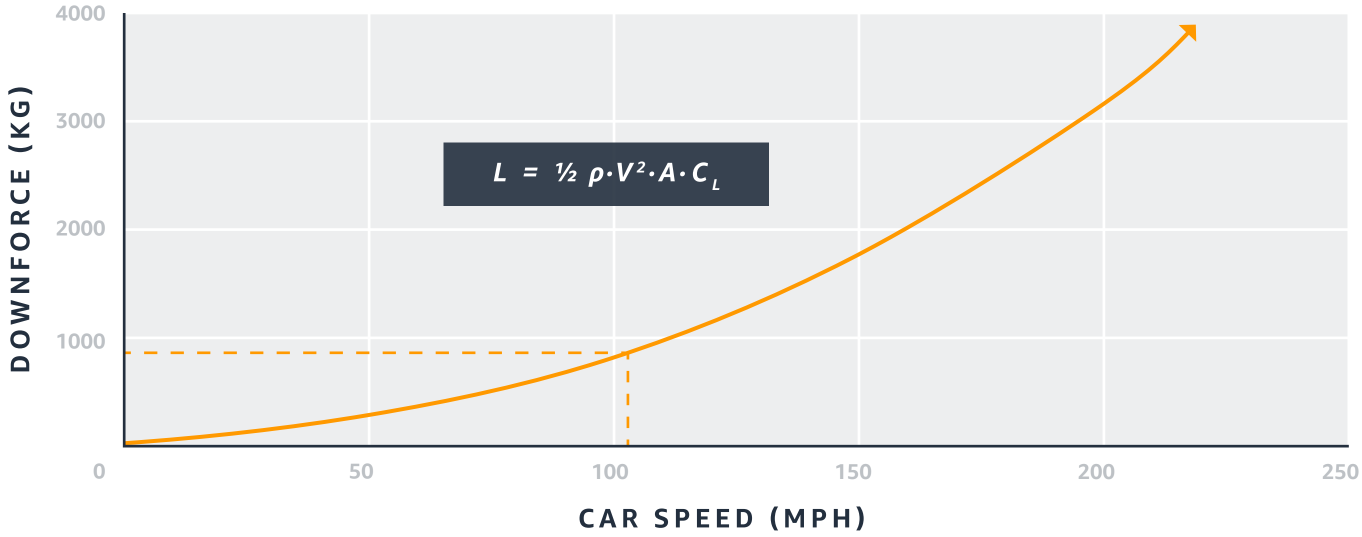
> We engaged our fan base and…the biggest thing that everybody wants is more wheel to wheel racing.
>
> **Rob Smedley**
> Director of Data Systems, F1

1982
Lotus unveils a new system of active suspension to improve downforce control. It is banned in 1994 for making the races too predictable

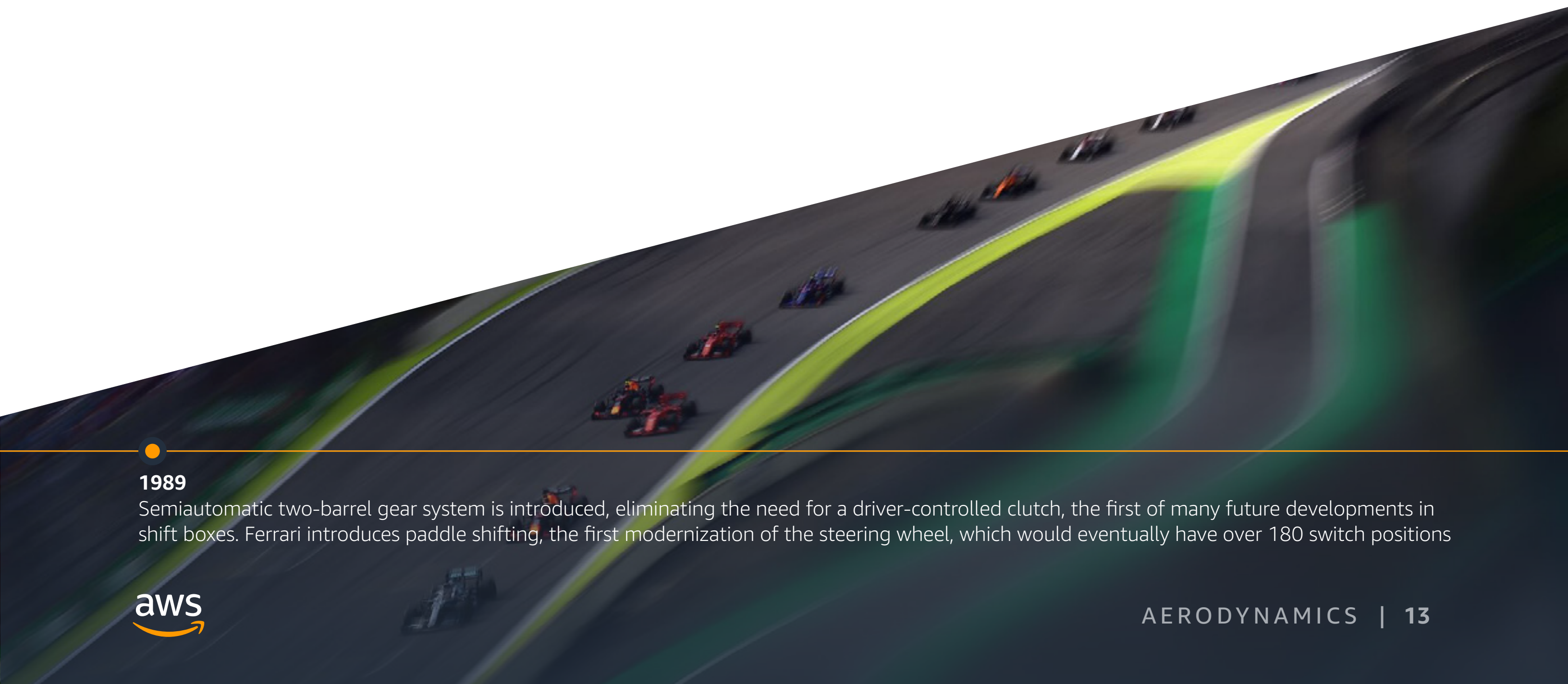
1984
The Austrian Grand Prix is first to feature only turbocharged cars

THE IMPACT OF DOWNFORCE

The nature of F1 aerodynamics is that the faster the car, the higher the downforce, according to the formula L = ½ ρ x V2 x A x CL where L is lift (in this case the downforce), ρ is air density, V is velocity, A is the reference area, and CL is the lift coefficient. To demonstrate how powerful this effect is, note that at only 100 mph, the downforce of a contemporary F1 car already matches the total vehicle weight, meaning the car could travel upside down!



But with such reliance on downforce to achieve high cornering speeds, any loss of downforce, as might be seen from following another car closely, is problematic for the racing spectacle. Predicting and addressing this conundrum is where computational fluid dynamics can help.



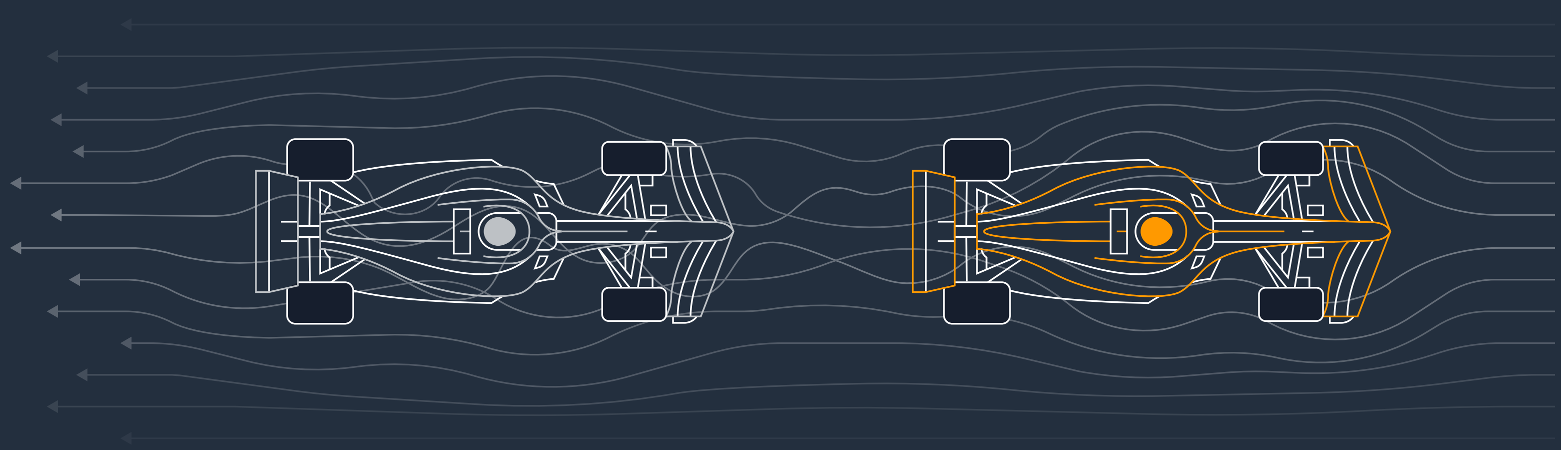
1989
Semiautomatic two-barrel gear system is introduced, eliminating the need for a driver-controlled clutch, the first of many future developments in shift boxes. Ferrari introduces paddle shifting, the first modernization of the steering wheel, which would eventually have over 180 switch positions

THE VIRTUAL WIND TUNNEL

The origins of aviation theory date back to the early 18th century, preceding the Wright Brothers' flight at Kitty Hawk by nearly 200 years. As more work was done to test the impacts of industrial design on drag coefficients, the first enclosed wind tunnel was operated in 1871, opening up a world of opportunity for understanding the mechanics of flight.

By moving air quickly past a stationary object, the wind tunnel is a controlled environment used to test everything from missiles and spacecraft to architecture and golf balls. But the high costs of running a wind tunnel, and the need to produce physical components for testing, make wind tunnel testing both expensive and time consuming.

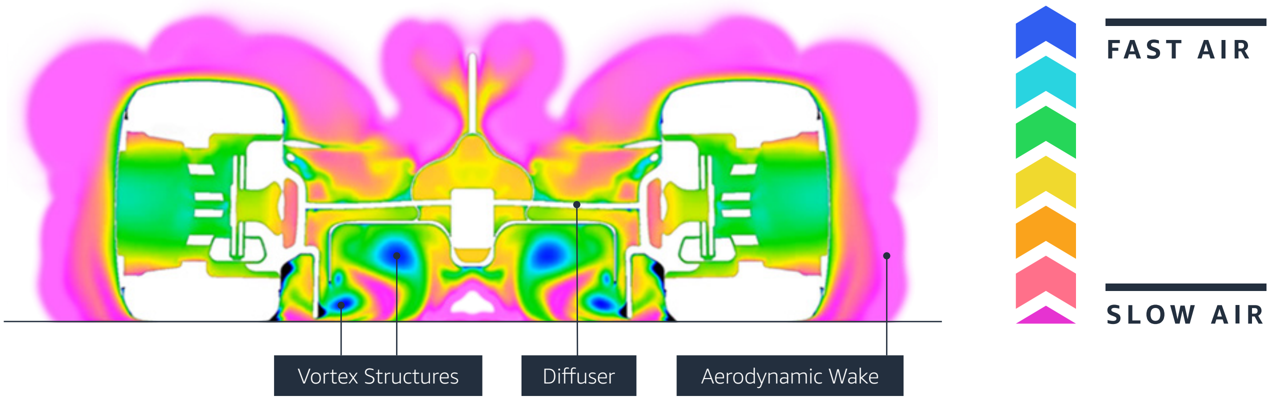
Enter **computational fluid dynamics**, or **CFD**—a virtual wind tunnel, allowing for accelerated experimentation on a computer to better understand flow physics. With the mathematical equations forming the foundations for CFD dating back nearly a century, modern CFD capability has followed technological progress with the advance of smaller and more powerful processing chipsets. Put simply, CFD uses a 3D environment with an X, Y, Z grid of virtual "boxes" called cells that calculate the free stream flow of "fluid" and the interaction of that fluid with surfaces defined by boundary conditions. The smaller the cells, the higher the density and more precise the results, but smaller cells require exponentially larger processing power. While F1 has been using CFD modeling for over 20 years, recent advancements in **high performance computing (HPC)** have dramatically increased the availability of computational power, opening up opportunities to rapidly solve problems that were previously considered impossible.



1998
New regulations introduced regarding narrower tracks and grooved tires

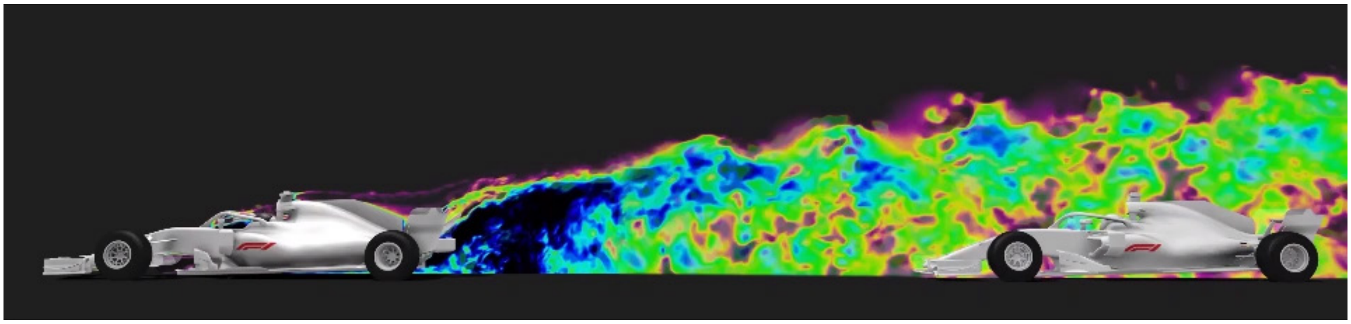
DEFINING THE PROBLEM

Let's look at some CFD slices showing total pressure (i.e., energy available) in the airflow immediately behind an F1 car. The pink fringes represent the extents of the wake—the green and blue areas represent the slower-moving, turbulent air that is especially problematic for the chase car.



And the closer the chase car gets to the lead car, the worse the effect. A car that is three car lengths behind will experience more than 30% loss in downforce.

But as that car approaches one car length in order to attempt an overtake, the problem gets even worse, with a downforce loss approaching 50%.



This is what racing engineers call "dirty air." To reduce this downforce loss created by the wake effect, F1 used AWS to look closely at how cars interact when racing together.

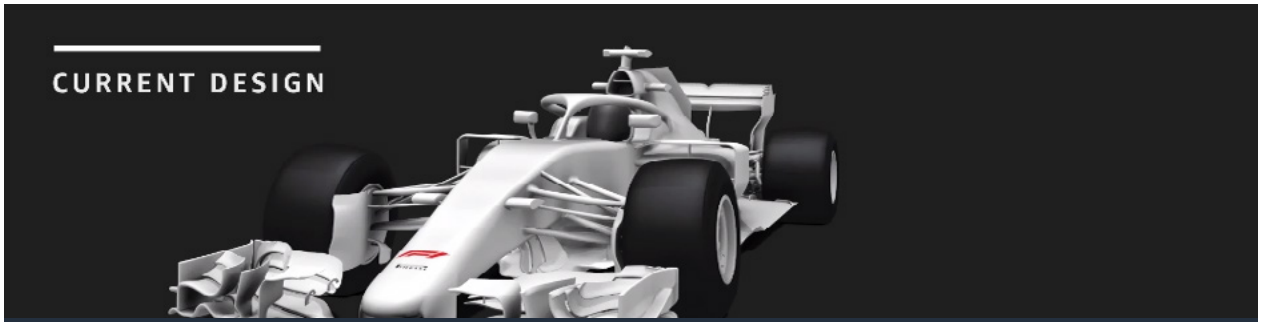
2009
Kinetic Energy Recovery System (KERS) introduced by F1 allowing cars to bank energy lost during breaking into a kinetic battery and redeploy at the push of a button, making overtaking easier and more exciting

2018
Halo, a rules-mandated armor to protect drivers from the impact of large pieces of flying debris, is introduced

REPOSITIONING THE WAKE

To solve this problem, F1 needed to continually test and develop two-car simulations on a virtual track in CFD. This would require a massive amount of compute power—far more than F1 would be able to run on-premises.

For context, running a basic "steady-state" (RANS) CFD simulation on a single car on the most powerful home computer with 95 million cells would take 40 days to produce a solution. By chaining 192 cores together, adding a second car and upgrading to a higher fidelity "unsteady" (DES) CFD simulation resulted in a 4 day turnaround, which was still far too slow to make rapid, iterative aerodynamic development practical. But by rebuilding the CFD modeling on Amazon HPC, using 1152 Amazon Elastic Compute Cloud (Amazon EC2) c5n instances, the team was able to cut this time to less than 12 hours. This allowed for faster turnaround of geometries aimed at lifting the aerodynamic wake in order to reduce the detrimental influence of dirty air on a following car.



This model shows the current cars with the front car leaving dirty air in the direct wake of the following car.

The redesign of the 2021 vehicles pushes the dirty air up and over the car in the rear. Note the additional space or pocket that is created by the wake.

2018
Formula 1 announces partnership with AWS and introduces F1 Insights to help fans understand the split-second decisions on the track, with Pit Strategy Battle and Battle Forecast using machine learning on AWS to predict overtakes

With six months of continual refinement, the system was delivering performance equivalent to that of a supercomputer costing millions of dollars. The team developed insights that led to a new car design for the 2021 racing season—the Challenge—featuring a brand-new bodywork design and running on 18-inch wheels with low profile tires for the first time.

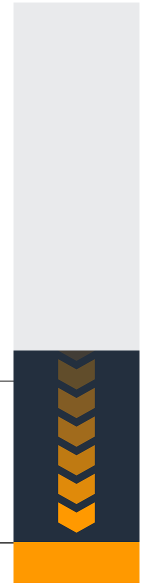
But the best part? The loss of downforce for a following distance of one car length was reduced from nearly 50% to around 10%, likely to significantly increase the prospect of wheel-to-wheel racing in 2021.

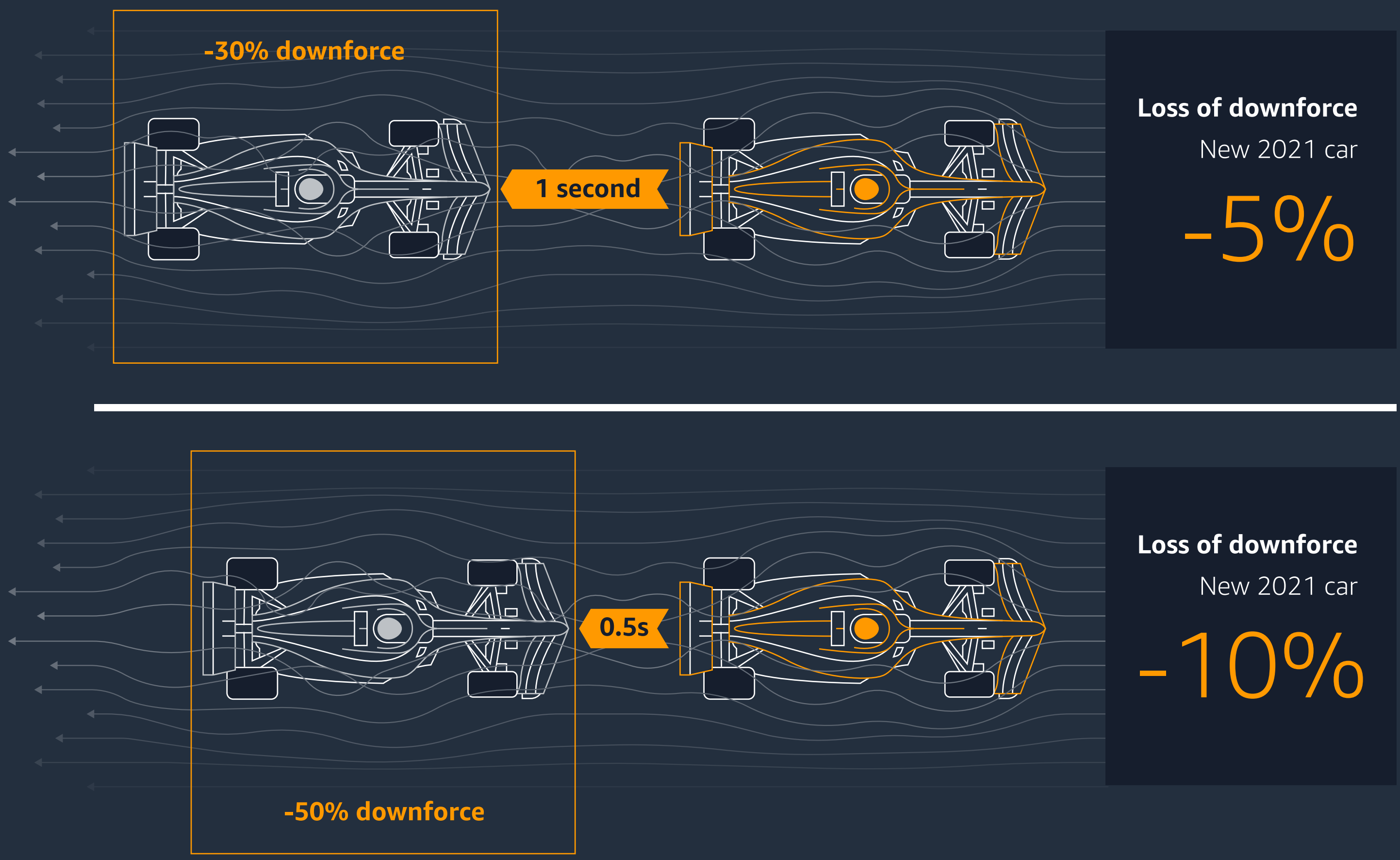
The loss of downforce for a .5 second following distance was reduced from

50%

to merely

10%





2019
Working with AWS, Formula 1 adds advancements to Pit Strategy Battle and Battle Forecast graphics and adds Tire Status graphic

2019
Formula 1 starts development of 2021 car to increase wheel-to-wheel action through computational fluid dynamics using Amazon HPC

CONCLUSION

GETTING STARTED WITH AWS

If F1 is continuing to innovate with AWS to take racing into the next generation, imagine what you can do for your business. With AWS, you have access to a range of professional services and training programs that let you tap into our experience to accelerate your initiatives. Here are three ways to get started.

GET HELP FROM THE PROS

AWS Professional Services is a global team of experts who can help you realize your desired business outcomes using the AWS Cloud.

Get started with Professional Services

ENGAGE WITH ML EXPERTS

The Amazon ML Solutions Lab pairs your team with our experts to build new machine learning solutions for your business.

Get started with the ML Solutions Lab

FIND THE RIGHT ML PARTNER

AWS machine learning partners offer a range of consulting services and technologies to help you explore and build the right solutions.

Find an AWS Partner

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